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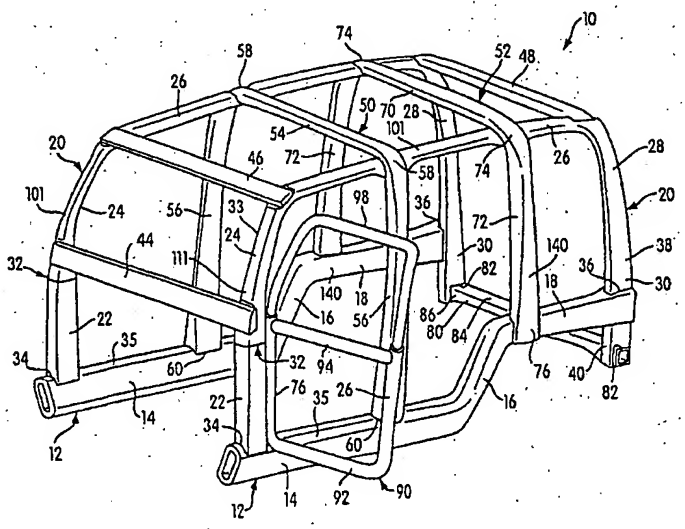

(57) Abstract

A space (10) for a motor vehicle comprising a first hydroformed, longitudinally extending tubular lower side rail (12) and a second hydroformed, longitudinally extending tubular lower side rail (12), the lower side rails being laterally spaced from one another and extending in generally parallel relation to one another. Also included is a pair of generally parallel, hydroformed tubular upper longitudinal structures (20), each being an integrally formed structure fixed to an associated one of the lower side rails. Each upper longitudinal structure has a longitudinally extending portion (26) constructed and arranged to support a roof of the motor vehicle, each longitudinally extending portion extending longitudinally between an upper end of an A pillar (24) of the space frame and an upper end of a rearward–most pillar (28) of the space frame. The hydroformed tubular upper longitudinal structures thus define lengths between the vehicle A pillars and the rearward–most pillars of the space frame. Laterally extending connecting structure connects the lower side rails to one another.

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HYDROFORMED SPACE FRAME AND METHOD OF MANUFACTURING THE SAME

Field Of The Invention

The present invention relates to space frames for motor vehicles.

Background Of The Invention

It is known in the automotive industry to provide a vehicle space frame which can be used to mount various components and body panels for the motor vehicle. Typically, the space frame is made from many frame members which are joined together by welding or other types of connections. The numerous connections that are typically required leads to tolerance build-up, which causes dimensional accuracy problems in the space frame.

Summary of Invention

It is desirable to provide a space frame that requires less parts and less connections than the conventional space frame, so that a space frame of greater dimensional accuracy can be achieved.

In accordance with one aspect of the present invention, there is provided a space frame for a motor vehicle, comprising a first hydroformed, longitudinally extending tubular lower side rail, and a second hydroformed, longitudinally extending tubular lower side rail, the lower side rails being laterally spaced from one another and extending in generally parallel relation to one another. Also included is a pair of generally parallel, hydroformed tubular upper longitudinal structures, each being an integrally formed structure fixed to an associated one of the lower side rails. Each upper longitudinal structure has a longitudinally extending portion constructed and arranged to support a roof of the motor vehicle, each longitudinally extending portion extending longitudinally between an upper end of an A pillar of the space frame and an upper end of a rearward-most pillar of the space frame. The hydroformed tubular upper longitudinal structures thus define lengths between the vehicle A pillars and the rearward-most pillars of the space frame. Laterally extending connecting structure connects the lower side rails to one another.

In accordance with another aspect of the invention, the following steps are performed: placing a tubular metal blank having a generally U-shaped configuration into a hydroforming die assembly, the die assembly having die surfaces defining a die cavity; providing pressurized fluid to an interior of the tubular metal blank so as to expand the blank into conformity with the die surfaces of the die cavity and thereby form a U-shaped hydroformed cross structure; positioning first and second lower side rails in laterally spaced, generally parallel relation to one another; connecting a first end of the hydroformed cross structure to the first lower side rail; and connecting a second end of the hydroformed cross structure to the second lower side rail.

Less parts are required in accordance with the space frame of the present invention and

therefore assembly is made much simpler.

Brief Description Of The Drawings

Figure 1 is a perspective view of a vehicle space frame manufactured in accordance with the principles of the present invention;

Figure 2 is a perspective view of a connection between the rearward cross-structure at one corner portion thereof and the associated uppermost straight portion of one of the longitudinal upper structures of the first embodiment illustrated in Figure 1;

Figures 3 and 4 are a cross-sectional view and a partial perspective view of the straight portion of the connection illustrated in Figure 2;

Figure 5 is a perspective view of a second embodiment of a vehicle space frame manufactured in accordance with the principles of the present invention;

Figures 6 and 7 are perspective views of various stages of assembly of space frame illustrated in Figure 5;

Figures 8-19 are illustrations of various views of the joints used in the embodiment of Figure 5; and

Figure 20 is a cross-sectional view of a hydroforming die assembly for illustrating the method in accordance with the present invention.

Detailed Description Of The Invention

Figure 1 is a perspective view of a vehicle space frame 10 manufactured in accordance with the principles of the present invention. The vehicle space frame 10 comprises a pair of laterally spaced, longitudinally extending lower side rails 12. Each of the side rails 12 has a relatively straight forward portion 14 which transitions into an upwardly and rearwardly sloping intermediate portion 16. In addition, each of the side rails 12 includes a generally straight rearward portion 18 extending rearwardly from the upper rearward end of the intermediate portion 16. The forward portion 14 and rearward portion 18 of the lower side rails 12 are disposed generally horizontally, and parallel to the ground and one another in an assembled vehicle. The intermediate portion 16 provides the rear "kick-up" for accommodating a rear wheel well.

The side rails 12 are each formed from a straight tubular blank, formed by conventional roll forming and seam welding, which are bent generally into the "S" configuration shown, then diametrically expanded, and shaped in any conventional hydroforming operation.

The lower side rails 12 have a varying cross-sectional configuration along its longitudinal extent. For example, towards the rearward portion 18, the lower side rails 12 preferably have a substantially rectangular cross-section. Towards the more forward portions 14, the lower side rails 12 have a substantially hexagonal cross-sectional configuration. Altering

the cross-sectional configuration of this member or other tubular hydroformed members disclosed herein can be accomplished without departure from the principles of the present invention.

The vehicle space frame 10 further includes a pair of hydroformed longitudinal upper structures 20 having a generally inverted U-shaped configuration. Each of the upper structures 20 includes a forwardly disposed, lower vertical portion 22, which transitions into an upwardly and rearwardly extending forward portion 24. Each of such portions 24 from the "A" pillar of the vehicle space frame. Each longitudinal upper structure 20 further includes an uppermost, longitudinally extending, generally straight portion 26, which transitions from extends rearwardly from the upwardly and rearwardly extending forward portions 24. The straight portions 26 constitute the bight portion of the generally inverted U-shaped configuration of the longitudinal upper structure 20. Towards the rearward portion of the longitudinal upper structures 20 are downwardly and rearwardly extending portions 28, which transition from the rearward portions of the uppermost straight portions 26. The downwardly and rearwardly extending portions form the space frame "D" pillars. Finally, the longitudinal upper structures 20 each terminate in respective lower vertical portions 30 extending downwardly from the downwardly and rearwardly extending portions 28.

As shown, each longitudinal upper structure 20 preferably has a generally rectangular cross-section throughout its extent. In addition, it should be appreciated that both of the longitudinal upper structures 20 have been hydroformed from a single tubular blank structure, preferably formed from two separately roll-formed tubular blanks which have been butt-welded to one another at butt-welded connection 32. In particular, the butt-welded connection 32 is performed prior to the hydroforming operation and connects two separate tubular blank members of different diameter to one another. More specifically, because the lower vertical portions 22 have a much greater diameter than the upwardly and rearwardly extending forward portions 24, these portions of each longitudinal upper structure 20 are preferably formed from blanks having substantially different diameters. The connection 32 can be accomplished by utilizing a reduction tool for reducing a diameter of one end of the tubular blank which eventually forms the lower vertical portion 22 so that such end of the blank can be butt-welded to the end of the smaller diameter roll-formed blank which eventually the rest of the longitudinal upper structure, as indicated by reference numeral 33. Alternately, a flaring or expansion tool can be used to expand the smaller diameter blank at the end thereof which is to form the lower forward end of the upwardly and rearwardly forward portion 24 so as to provide the end of that blank portion, which forms portion 33, with substantially the same diameter as the adjoining end of the blank which is to form the lower vertical portion 22. The butt-welding operation can be

performed either before or after the relevant tubular blank portions are bent into a U-shaped configuration. Bending of the blank is conducted prior to hydroforming. After the blank portions are butt welded to one another to form a complete single blank structure, the single blank structure is hydroformed as a single unit into the associated longitudinal upper structure 20.

The lower edge 34 of each of the lower vertical portions 22 is contoured to form-fittingly receive the corresponding upper surface portions 35 of the forward portion 14 of the lower side rails 12. The lower edges 34 are cut into such form-fitting configuration after the hydroforming operation is completed. The edges 34 are positioned on upper surface portions 35 and preferably mig-welded in place.

The rearward portions 18 of the lower side rails 12 terminate in cut-out edges 36. The edges 36 are each constructed and arranged to receive a corner portion of the vertical portion 30 of the associated upper longitudinal structure 20. More specifically, the vertical portion 30 each have a rectangular cross-section. The edges 36 of the lower side rails 12 are formed as cut-outs so as to engage the outboard facing surface 38 and the forwardly facing surface 40 of the vertical portion 30. The edge 36 is preferably mig-welded to the vertical portion 30.

A plurality of cross-members are interconnected between the longitudinal upper structures 20. A first cross-member 44 comprises a hydroformed tubular section connected between the longitudinal upper structures 20, preferably towards the lower portions of the upwardly and rearwardly extending forward portions 24 and immediately above the butt-welded connections 32. Similarly, a cross-member 46 connects the two longitudinal upper structures 20, generally at the bending or arcuate transition between the upwardly and rearwardly extending forward portions 24 and the uppermost straight portions 26. In addition, a rearward cross-member 48 extends between the longitudinal upper structures 20, generally at the bending or arcuate transition between the uppermost straight portions 26 and the downwardly and rearwardly extending portions 28. Preferably, each of these cross-members 44, 46, 48 has a generally rectangular cross-sectional configuration and is hydroformed from a circular tubular blank in conventional fashion.

The cross-members 44, 46 and 48 have opposite ends thereof disposed in overlapping or overlying relation with adjoining portions of upper structures 20, and are received in recesses which are hydroformed into the exterior configuration of longitudinal upper structures 20 and mig-welded in place.

A pair of inverted U-shaped hydroformed cross-member structures 50 and 52 are disposed between the cross-members 46 and 48. The forwardly disposed U-shaped cross structure 50 has a generally horizontally disposed bight portion 54 extending in a cross-car

direction, and a pair of leg portions 56 extending downwardly from the opposite ends of the bight portion 54. Corner portions 58 of the cross-structure 50 form the transition between the bight portion 54 and the respective leg portions 56. The corner portions 58 are disposed in overlying or overlapping relation with adjacent, underlying portions of the uppermost straight portions 26. The bottom edges 60 of the leg portions 56 are cut so as to be form fitting with respect to the adjacent upper surfaces 35 of the respective lower side rails 12. The edges 60 are then mig-welded to the upper surface of the lower side rails 12.

The corner portions 58 are received in hydroformed recesses formed in the exterior configuration of the uppermost straight portions 26 to form overlapping glove-joints with the associated uppermost straight portions 26 and mig-welded in place.

The rearward cross-structure 52 comprises a bight portion 70, which is substantially horizontally disposed and extends in the cross-car direction. The bight portion 52 transitions into vertically downwardly extending leg portions 72 from the opposite ends of the bight portion 70. Corner portions 74 form the transition between the bight portion 70 and the respective leg portions 72. The corner portions 74 are disposed in overlapping or overlying relation to adjacent portions of the uppermost straight portions 26. In particular, the corner portions 74 are disposed in hydroformed recesses formed in the exterior configuration of the uppermost straight portions 26. The leg portions 72 have ends 76 thereof received within recesses which are hydroformed in the associated lower side rails 12 and mig-welded in place. Again, the recess is formed within the lower side rails 12 for receiving the end portions 76.

It should be appreciated that the upper portions of the legs 56 of cross-structure 50 form the "B" pillars of the space frame. Similarly, the upper portions of the legs 72 of the more rearwardly disposed cross-structure 52 form the "C" pillars. Finally, the downwardly and rearwardly extending portion 28 of each of the longitudinal upward structures 20 forms the "D" pillars.

A lower rearward cross-member 80 is hydroformed into a rectangular cross-sectional configuration, and extends between the lower ends of the rearward vertical portions 30 of the longitudinal upper structure 20. The vertical portions 30 are cut so as to be provided with a cornered edge 82 which is constructed and arranged to engage the upper surface 84 and forwardly facing surface 86 of the rearward cross-structure 80. The edges 82 are welded to the surfaces 84 and 86 preferably by a mig-welding operation.

The vehicle space frame assembly 10 further includes a door structure 90, including a hydroformed lower U-shaped tubular member 92, a straight tubular cross-member 94 which is welded adjacent to the ends of the vertical legs 96 of the U-shaped member 92 and an inverted U-shaped hydroformed member 98 having the opposite leg portions thereof telescopingly

received within the tubular ends of the U-shaped member 92.

Referring to Figures 2-4, the recess 100 illustrated is formed as a result of the hydroforming process. A net pad is provided as part of a hydroforming dye assembly so as to give the particular configuration illustrated. As shown, the recess 100 is formed in an upper wall 101 of straight portion 26. The upper wall 101 forms the recess 101 with opposite sloping faces 102, and an adjoining straight, horizontally disposed wall portion 104. It can be appreciated that this particular configuration for the recess is not critical. The sloping faces 102 may be more vertically disposed, so as to form a substantially right angle with respect to the surface 104. The recess 100 is formed such that the bottom wall of 110 of the hydroformed straight portion 26 is formed so as to have a corresponding configuration in relation to the upper wall 101. The bottom wall portion 110 includes downwardly and inwardly sloping wall portions 112, which are adjoined by substantially horizontally disposed wall portion 114. The wall portion 114 has a greater length than the wall portion 104. In addition, the sloping wall portions 112 preferably slope to a lesser extent than the angle at which the wall portions 102 slope. As a result, the distance between the upper wall portion 101 and the lower wall portion 110 is substantially less at areas of the recess 100 than immediately surrounding or adjacent portions on opposite sides of the recess. While the lower wall 110 formed at the recess 100 generally conforms to the configuration of the upper wall 101, it is contemplated that the lower wall 110 may be substantially straight.

The preferred configuration for the upper cross-structure 52 is shown, which incorporates a downwardly facing recess at the corner portion 74. The recess has generally a complementary configuration as the recess 101 and has a horizontal or straight surface which rests upon and is fixed to the upwardly facing surface 104 of the uppermost straight portion 26. At the downwardly facing recess provided in cross-structure 52, the thickness between the horizontal wall portions 120, and 122 is less at the recessed portion of the cross-structure 52 beneath the corner portion 74 is substantially less than the thickness between such wall portions 120, 122 on opposite sides of the recess.

As a result of the formation of the overlapping recesses formed in the longitudinal straight portions 26 and the corner portions 74 of the cross-structure 52, the overlapping intersections forming the connections between the cross-structure 52 and laterally spaced uppermost straight portions 26 can be made so as to have a reduced cross-sectional profile, yet maintaining a relatively high ratio of contact area between the members. The desired profile could also be achieved if only one of the overlapping members is provided with a recess, although it is preferred for both overlapping portions to be provided with such a recess.

A similar overlapping joint connection having recesses is provided at the connection of

the cross-structure 50 with the uppermost straight portions 26, generally beneath corner portions 58 of the cross-structure 50.

Similar recesses are formed in the longitudinal upper structures 20 so as to form connections with opposite ends of the cross-members 44, 46, and 48. However, at such connections, recesses formed within the longitudinal upper structures 20 are provided in the upper or outwardly facing wall portion 111 only. The opposing wall portion at these connections is substantially straight, as contemplated in the discussions above. In addition, the cross members 44, 46, and 48 are not provided with any recess, but are received within recesses at opposite ends to form reduced profile welded connections.

Finally, the same type of connection is fused to connect the bottom portions 76 of the cross-structure 52, which are received and welded within a hydroformed recesses formed within the lower side rails 12. Again, only one of the wall portions is configured in forming the recess, and the opposite wall portion is substantially flat or continuous with adjoining wall portions, as can be appreciated from area 140 in Figure 1.

Since the frame members described above are all hydroformed, a precisely configured space frame can be achieved. For example, because the upper longitudinal structures 20 are hydroformed as a single unit, the desired distance between the forward lower vertical portions 22 and the rearward lower vertical portions 30 (or between the "A" pillar and "D" pillar can be made within a higher degree of accuracy and precision in comparison to constructions in which the parts are separately formed and then connected. The same is true in the cross-car direction, e.g., the distance between the "C" pillars or between the "B" pillars is precisely achieved in accordance with the accuracy to which the cross structures 50 and 52 can be hydroformed.

Figure 5 is a perspective view of a second embodiment of the present invention. Figure 5 illustrates a space frame 200, which incorporates a vehicle cage 210 and a front end module assembly 400 connected to the front end of the vehicle cage.

The vehicle cage 210 is similar in many respects to the space frame 10 of the first embodiment. The vehicle cage 210 comprises a pair of laterally spaced, longitudinally extending lower side rails 212. Each of the side rails 212 has a relatively straight forward portion 214 which transitions into an upwardly and rearwardly sloping portion 216. In addition, each of the side rails 212 includes a generally straight or slightly arcuate portion 218 extending rearwardly from the upper rearward end of the intermediate portion 216. Unlike the first embodiment, however, the side rails also include a downwardly and then rearwardly extending rearward portion 219 forming the rearward end of the side rails 212. The portions 216, 218, and 219 provide the rear "kick-up" for accommodating a rear wheel well.

The side rails 212 are each formed from a straight tubular blank, preferably formed by

conventional roll forming and seam welding, which are bent generally into the "S" configuration shown, then diametrically expanded, and shaped in any conventional hydroforming operation.

The vehicle space frame 210 further includes a pair of hydroformed longitudinal upper structures 220. Each of the upper structures 220 includes a forwardly disposed, lower vertical portion 222, which transitions into an upwardly and rearwardly extending forward portion 224. The portions 222 and 224 form the "A" pillar of the vehicle space frame 210. Each longitudinal upper structure 220 further includes an uppermost, longitudinally extending, generally straight portion 226, which transitions from extends rearwardly from the upwardly and rearwardly extending forward portions 224.

Each longitudinal structure 220 terminates towards the rearward portion of the generally straight portion 226, where it is welded to a rear aperture ring 227 of the vehicle cage. The rear aperture ring 227 comprises two U-shaped tubular hydroformed members 229 and 231. The upper U-shaped member 229 is inverted and is connected at opposite ends thereof to the opposite ends of the upright lower U-shaped member 231 at a glove joint 237. More particularly, opposite legs 243 of the upper U-shaped member 229 terminate in cross sectional diameter portion that is smaller than the cross-sectional diameter of the opposite ends of the opposite legs 241 of lower U-shaped member 231. Thus, the end portions of the legs 243 of the upper U-shaped member 229 are received within the open ends of the lower U-shaped member 231 and then welded in place. The portions of the upper U-shaped member 229 immediately above the end portions that are received within the legs 241 of lower member 231 are diametrically expanded so as to form flange surfaces that engage the mating upper edges of the open ends of the upwardly extending legs 241 of the lower member 231, so as to limit the extent to which the legs 243 of upper member 229 can extend within the legs of lower member 231. This rear aperture ring 227 defines a rear opening for a vehicle rear door or lift gate.

The legs 243 of the upper U-shaped member 229 and the legs 241 of the lower U-shaped member 231 cooperate to form laterally spaced, generally parallel, and vertically extending D pillars 228 of the frame assembly 200. The upper U-shaped member 229 has a laterally extending bight portion 248 connected between the leg portions 243.

The aperture ring 227, being formed from two U-shaped members provides enhanced dynamic stability of the space frame from a matchboxing standpoint, to prevent twisting of the frame in its application environment.

The junctures between the legs 243 and the bight portion 248 are joined to the rear ends of the generally straight portions 226 by a welded connection. Each upper longitudinal member 220 comprises an entire "A" pillar and also defines the portion at which the upper end of an associated "D" pillar 228 is connected. Thus, the hydroformed tubular structures 220 in

conjunction with the aperture ring 227 define both a longitudinal dimension and a cross-vehicle dimension of the vehicle cage 210.

As shown, the leg portions 241 of the lower U-shaped member 231 are connected by a bight portion 245. The junctures or transitions between the bight portion 245 and the opposing leg portions 241 are joined at a welded connection with rearward ends of the side rails 212. A notch 213 (Figure 7) is cut in the end of each side rail 212 to nestingly receive the lower U-shaped member 231.

Referring to Figure 6, a plurality of cross-members are interconnected between the longitudinal upper structures 220. In particular, a first cross-member 244 comprises a hydroformed tubular section having a substantially rectangular cross-section and connected between the longitudinal upper structures 220, preferably between the lower portion 222 and upwardly and rearwardly extending portion 224 of the "A" pillar, and immediately above the butt-welded connections 232. Similarly, a cross-member 246 connects the two longitudinal upper structures 220, generally between the upper ends of the "A" pillars.

Referring to Figure 15, the cross-members 244, 246 have opposite ends joined to the upper structures 220. These joints are formed by welded connections. Recesses are formed in the longitudinal upper structures 220, preferably a hydroforming operation, as was described with the first embodiment. The opposite ends of cross members 244, 246 are received in the recesses and welded place. The joints 247 may be facilitated by a structural adhesive connection, which can be used in lieu of, or in conjunction with welding.

Referring back to Figures 5 and 6, a pair of inverted U-shaped hydroformed cross-member structures 250 and 252 are disposed between the cross-members 246 and the rear aperture ring 227. The forwardly disposed U-shaped cross structure 250 has a generally horizontally disposed bight portion 254 extending in a cross-car direction, and a pair of leg portions 256 extending downwardly from the opposite ends of the bight portion 254. Corner portions 258 of the cross-structure 250 form the transition between the bight portion 254 and the respective leg portions 256. The corner portions 258 are disposed in overlying or overlapping relation with adjacent, underlying portions of the uppermost straight portions 226. The corner portions are preferably adhered to the straight portions by a structural adhesive.

The rearward cross-structure 252 comprises a bight portion 270, which is substantially horizontally disposed and extends in the cross-car direction. The bight portion 252 transitions into vertically downwardly extending leg portions 272 from the opposite ends of the bight portion 270. Corner portions 274 form the transition between the bight portion 270 and the respective leg portions 272. The corner portions 274 are disposed in overlapping or overlying relation to adjacent portions of the uppermost straight portions 226, and are preferably joined

by a structural adhesive.

The corner portions 258 and/or 274 may be disposed in hydroformed recesses formed in the exterior configuration of the uppermost straight portions 226 as in the first embodiment.

Referring to Figure 10, the bottom end portions 260 of the leg portions 256 are received within openings in the side rails 212 and welded in place.

Referring to Figure 12, the leg portions 272 have ends 276 thereof received within openings 277 which are punched in the associated lower side rails 212 and mig-welded in place.

It should be appreciated that at each of the overlapping joints discussed above in the second embodiment, net pads can be used in the hydroforming die for forming recesses in the hydroformed tubes to facilitate joining of the parts, as can be appreciated from the discussions of the first embodiment, particularly with respect to Figures 2-4. It should be appreciated that this type of connection can be at any joint, and not only at the corners 258 and 274.

As shown in Figures 5 and 6, each longitudinal upper structure 220 preferably has an irregular, almost pyramidal or trapezoidal cross-section. In addition, it should be appreciated that both of the longitudinal upper structures 220 have been hydroformed from a single tubular blank structure, preferably formed from two separately roll-formed tubular blanks which have been butt-welded to one another at butt-welded connection 232. In particular, as described with the first embodiment, the butt-welded connection 232 is performed prior to the hydroforming operation and connects two separate tubular blank members of different diameter to one another.

As described with the first embodiment, the lower side rails 212 have a varying cross-sectional configuration along its longitudinal extent. Preferably, the side rails 212 extend generally from a position immediately forward of the lower portions 222 of the "A" pillars to the rearward end of the cage 210. The forward ends of the side rails 212 are joined to front side rails 412 of the front frame assembly 400.

Preferably, the side rails 212 are formed from formed from two separately roll-formed tubular blanks which have been butt-welded to one another at butt-welded connection or a tongue in groove connection 247. The butt-welded connection 247 is performed prior to the hydroforming operation and connects two separate tubular blank members of different diameter to one another as discussed above in relation to the "A" pillar.

A plurality of additional cross frame members 255, 257, and 259 are also connected between the side rails 212. The cross member 259 constitutes a riser-floor pan support structure. The cross member 259 is connected between the side rails 212 at portions of the side rails immediately forwardly of the rear kick-up for accommodating the rear wheels. The ends of the cross member 259 are provided with notches 277 that are formed to nestingly receive the

underside of the side rails 212. The cross member 259 is welded to the side rails 212.

As shown in Figure 9, the lower portion 234 of each of the lower vertical portions 222 is received in a hole 235 in the upper wall and a hole 249 in the lower wall of the forward portion 214 of each lower side rail 212. The holes 235 and 249 are formed either during the hydroforming process in what is known in the art as a hydropiercing operation, or cut into such form-fitting configuration after the hydroforming operation is completed. The lower portions 234 are positioned as shown and then are preferably mig-welded. A cross frame member 251 connects the lower side rails 212 to one another by an L-shaped bracket 253. The bracket connects the cross frame member 251 at the same longitudinal location as the-A pillar lower portion 222, relative to the longitudinal direction of the side rails 212. The frame member 251 is at least partially overlapping with the lower portion 222 relative to the longitudinal direction of the side rails 212. Optionally, the opposite ends of the cross member 255 can be received within a recess in the lower wall of each of the side rails 212 and welded in place.

In order to improve rigidity or structural integrity of the space frame 210, certain joints can be reinforced using a gusset or bracket 294 as illustrated in Figure 8. In particular, the joints between the vertically extending members and the lower longitudinal members can be reinforced using a horseshoe shaped bracket as illustrated.

Referring to Figure 11, the vehicle cage 210 is shown in combination with a vehicle front door 267. The door 267 incorporates a hydroformed lower cross member 269, which is welded to a door outer panel 271. A peripheral rubber seal structure 273 is fixed to the door 267 and surrounds the door to form a door seal with the lower rail, or an aesthetic covering therefor, when the door is closed. The lower cross member 269 form the lower portion of a door frame structure that is similar to the door frame structure 90 illustrated in Figure 1. The seal structure 273 also forms a seal with the "A" pillar when the door is closed. A portion of a forwardly disposed vertical structure 275 of the door 267 forms the downwardly extending forward leg portion of the door structure, similar to the forward portion 75 of the door upper frame structure 98 illustrated in Figure 1. The structure thus forms part of an inverted, tubular hydroformed structure, similar to the structure 98 of Figure 1.

Referring to Figures 13 and 14, the front end module 400 is preferably made from a plurality of hydroformed members, including lower front frame rail members 412 connected with the side rails 212 in a glove fit. A pair of upper longitudinally extending members 420 define the upper front end of the vehicle for supporting body panels including the front hood. Each member 420 is provided with a recess 422 in the upper and lower surfaces and formed in the opposite ends thereof for receiving the A pillar of the space frame, and is then welded in place. Because the members 420 are connected with the A pillars, the A pillars will absorb

longitudinal force applied to the members 420. Similarly, longitudinal forces applied to the front rail members 412 will be absorbed by the rail members 212.

Figure 16 illustrates the manner in which a rear quarter panel Q would be mounted on the space frame 200. Preferably, the rear quarter panel would be fixed to the C-pillar 272 and to the rearward portion of the longitudinally extending portion 226 by a structural adhesive A.

Referring to Figure 17, a vehicle roof R can be mounted to the longitudinally extending portion 226 by a bracket B. The bracket B may also support a corner panel P. A front driver's side door D is illustrated, the parts of which can be appreciated from the more detailed description of a rear passenger door.

The interface between the vehicle C-pillar and the rear passenger door 374, and the connection of the C-pillar 272 with the rear quarter panel 375 is illustrated in Figure 18 Preferably, the door 374 has a peripheral hydroformed door frame 376 manufactured by hydroforming two U-shaped tubular members in accordance with the teachings above in relation to the door in the first embodiment. The frame 376 is welded to outer door sheet metal 377. A door seal 378 and door window 379 are also shown.

Figure 20 is a cross sectional view of a hydroforming die assembly for illustrating the method of the present invention. The shape of the die cavity in accordance with the present invention is particularly adapted to the shape of the new and advantageous tubular parts now contemplated. Figure 20 is representative in nature and illustrates two hydroforming ram assemblies 500 and 502, which have outer ram members, respectively, which are movable to engage and seal opposite ends of a tubular blank 510, which has been bent (for example in a CNC bending machine) to fit within a die cavity 512 of a hydroforming die structure 514. The blank 510 can represent any U-shaped or inverted U-shaped member discussed above. The tube 510 is preferably immersed in a water bath so as to be filled with hydroforming fluid. The rams 500 and 502 include hydraulic intensifiers, which can intensify the hydroforming fluid to expand the tube into conformity with the die surfaces. The outer rams 504 and 506 push inwardly into the die structure so as create metal flow within the blank 510 so as to replenish or maintain the wall thickness of final tube part within about +/- 10% of the original wall thickness of the blank (i.e., to compensate for wall thinning during diametric expansion of the tube).

Briefly, in accordance with the hydroforming methodology of the present invention, a first tubular metal blank having a generally U-shaped configuration is placed into the hydroforming die assembly, said die assembly having die surfaces defining a die cavity. The ends of the tube blank are sealed, and hydraulic fluid is pressurized by an intensifier within the interior of said first tubular metal blank so as to expand said blank into conformity with the die surfaces of said die cavity and thereby form a first of the hydroformed upper longitudinal

structures, such as longitudinal structures 20 of the first embodiment or 220 of the second embodiment. A second tubular metal blank having a generally U-shaped configuration is also placed into a hydroforming die assembly, and pressurized fluid expands this second tubular metal blank so as to expand said blank into conformity with the die surfaces of the die cavity and thereby form a second of the hydroformed upper longitudinal structures (20 or 220). The first and second upper longitudinal structures each comprises at least one pillar of the space frame. For example, each upper longitudinal structure 20 of the first embodiment comprises both the A-pillar and the D-pillar, while in the second embodiment, each structure 220 forms a respective A-pillar. First and second lower side rails (12 or 212) are provided, and the at least one pillar of the first hydroformed upper longitudinal structure is connected to a first of the spaced lower side rails. The at least one pillar of each second hydroformed upper longitudinal structure (20 or 220) is connected to a second of the spaced lower side rails. The first and second lower side rails are positioned in laterally spaced relation to one another. The first and second lower side rails (12 or 212) are connected to one another with laterally extending connecting structure, for example, the cross member 80 of the first embodiment and cross members 251, 255, and 257 of the second embodiment.

The present invention also contemplates that the U-shaped cross structures (e.g., 50, 52, 250, and 252 are hydroformed by placing a tubular metal blank having a generally U-shaped configuration into a hydroforming die assembly and then internally pressurized and expanded to conform to the die surfaces. The first and second lower side rails are positioned in laterally spaced relation to one another. A first end of the hydroformed cross structure is connected to the first lower side rail, and a second end of the hydroformed cross structure is connected to the second lower side rail.

It is to be understood that each of the hydroformed tubular members discussed herein is formed from an integral tubular blank from a tube stock. Preferably, the blank is formed by conventional roll forming and subsequent seam welding technology. The tubular blank is then expanded into conformity with the surfaces defining the hydroforming die cavity, so as to form the tube with a shape corresponding to the desired shape for the part. Preferably, the ends of the tubular blank are forced inwardly toward one another during the hydroforming operation so as to replenish or maintain the wall thickness of the formed part within a predetermined range of the wall thickness of the initial tubular blank. It should thus also be appreciated that each of the hydroformed tubular parts disclosed in the present application is formed from a single tubular member which is positioned within the hydroforming die, although the single tubular blank member may itself be formed by joining two or more tubular members to one another (e.g., by but welding the tubular blank members in end-to-end fashion) before it is placed in the

hydroforming die to be hydroformed. In this sense, each hydroformed tubular structure disclosed herein is an integrally formed tubular structure, meaning that it has been hydroformed into a singular tubular structure that corresponds to a desired shape, and does not comprises a plurality of tubular structures fixed to one another. In addition, when formed in accordance with the preferred method, each of the hydroformed tubular structures in accordance with the present invention has only a single longitudinal seam weld, which weld was performed in creating the original tubular blank. This is distinct from more conventional tubular frame members, which comprise two C-shaped or clam-shell halves welded to one another in facing relation along two seams.

While the invention has been disclosed and described with reference with a limited number of embodiments, it will be apparent that variations and modifications may be made thereto without departure from the spirit and scope of the invention. Therefore, the following claims are intended to cover all such modifications, variations, and equivalents thereof in accordance with the principles and advantages noted herein.

WHAT IS CLAIMED IS:

1. A space frame for a motor vehicle, comprising:

a first longitudinally extending lower side rail and a second longitudinally extending lower side rail;

a pair of hydroformed tubular upper longitudinal structures, each connected to an associated one of said lower side rails, each upper longitudinal structure extending upwardly from said associated lower side rail so as to form an A pillar of said space frame, each upper longitudinal structure having a longitudinally extending portion extending rearwardly from said A pillar portion, each upper longitudinal structure extending downwardly to said associated lower side rail to form a rearward-most pillar of said space frame, said hydroformed tubular upper longitudinal structures thus defining lengths between said A pillar and said rearward-most pillar of said space frame; and

laterally extending connecting structure connected to said lower side rails spacing said lower rails from one another to extend in generally parallel relation to one another.

2. The space frame according to claim 1, further comprising a hydroformed tubular cross structure connected at a first end thereof to said first lower side rail and connected at a second end thereof to said second lower side rail, said cross structure extending upwardly from a first of said opposite ends thereof so as to form a first B pillar, said cross structure having a laterally extending portion extending across said vehicle frame from said first B pillar, said cross structure extending downwardly from said laterally extending portion towards a second of said opposite ends thereof so as to form a second B pillar, said hydroformed tubular cross structure thus defining a length between said B pillars of said space frame.

3. The space frame according to claim 2, wherein said lower side rails comprise hydroformed tubular structures.

4. The space frame according to claim 3, wherein said hydroformed tubular structure is disposed in overlapping relation with said longitudinally extending portion of each of said hydroformed tubular upper longitudinal structures, said longitudinally extending portion of each of said hydroformed tubular upper longitudinal structures being provided with a recess, and wherein said hydroformed tubular structure is disposed within said recess.

5. A space frame for a motor vehicle according to claim 4, wherein said laterally extending connecting structure comprises a hydroformed tubular member connected between said lower side rails.

6. A space frame according to claim 5, further comprising upper connecting members, said upper connecting members extending laterally between said upper longitudinal structures and connecting said upper longitudinal structures to one another.

7. A space frame according to claim 1, further comprising a door structure, said door structure being pivotally connected with one of said upper longitudinal structures at a portion thereof that extends upwardly from said forward end portion of said associated lower side rail and that is below said A pillar.

8. A space frame according to claim 7, wherein said door structure comprises a plurality of hydroformed tubular members, said hydroformed tubular members being connected end-to-end to form a periphery of said door structure.

9. A space frame according to claim 8, wherein said door structure comprises a first U-shaped tubular member and a second U-shaped tubular member, said second U-shaped tubular member being inverted relative to said first U-shaped tubular member and having opposite ends connected to respective opposite ends of said first U-shaped tubular member.

10. A space frame for a motor vehicle, comprising:

a first hydroformed, longitudinally extending tubular lower side rail, and a second hydroformed, longitudinally extending tubular lower side rail, said lower side rails being laterally spaced from one another and extending in generally parallel relation to one another;

a pair of generally parallel, hydroformed tubular upper longitudinal structures, each being an integrally formed structure fixed to an associated one of said lower side rails, each upper longitudinal structure having a longitudinally extending portion constructed and arranged to support a roof of said motor vehicle, each longitudinally extending portion extending longitudinally between an upper end of an A pillar of said space frame and an upper end of a rearward-most pillar of said space frame, said hydroformed tubular upper longitudinal structures thus defining lengths between said vehicle A pillars and said rearward-most pillars of said space frame; and

laterally extending connecting structure constructed and arranged to connect said lower side rails to one another.

11. A space frame according to claim 10, wherein each said upper longitudinal structure includes a vertically extending portion connecting said longitudinally extending portion thereof with the associated side rail thereof, each said vertically extending portion constituting an A pillar of said space frame.

12. A space frame according to claim 11, further comprising a pair of vertically extending structures connecting rearward ends of said longitudinally extending portions with rearward ends of the associated side rails, said vertically extending structures constituting the rearward-most pillars of said space frame.

13. A space frame according to claim 12, wherein said vertically extending structures are integrally formed as part of said upper longitudinal structures.

14. A space frame according to claim 13, wherein said vertically extending structures form part of a rearward aperture ring of said space frame, said rearward aperture ring comprising a lower U-shaped member and an upper inverted U-shaped member, said lower U-shaped member having first and second leg portions connected by a bight portion, said upper inverted U-shaped member having first and second leg portions connected by a bight portion, wherein the first leg of said lower U-shaped member is connected to the first leg of said upper inverted U-shaped member so that said connected first legs constitute one of said vertically extending structures forming one of said rearward-most pillars, and wherein the second leg of said lower U-shaped member is connected to the second leg of said upper inverted U-shaped member so that said connected second legs constitute another of said vertically extending structures forming another of said rearward-most pillars.

15. A space frame according to claim 10 wherein said laterally extending connecting structure includes a rear aperture ring connected to rearward ends of said lower side rails and to rearward ends of said upper longitudinal structures.

16. A space frame according to claim 15 wherein said rear aperture ring comprising first and second U-shaped members, each of said U-shaped members being of a tubular, hydroformed construction, wherein each leg of said first U-shaped member is connected with an associated one leg of said second U-shaped member to define a rear aperture of said space frame.

17. A space frame according to claim 16, wherein said first U-shaped member is disposed in a upright U-shape configuration, and wherein said second U-shaped member is disposed in an inverted U-shape configuration.

18. A method of forming space frame for a motor vehicle, said method comprising:

hydroforming a first upper longitudinal structure;

hydroforming a second upper longitudinal structure;

providing first and second lower side rails;

connecting said first upper longitudinal structure to opposite end portions of a first of said spaced lower side rails;

connecting said second upper longitudinal structure to opposite end portions of a second of said spaced lower side rails;

positioning said first and second lower side rails in laterally spaced, generally parallel relation to one another; and

connecting said first and second lower side rails to one another with laterally extending connecting structure.

19. A method according to claim 18, further comprising: mounting body panels to said first and second upper longitudinal structures.

20. A method according to claim 18, wherein said step of connecting said first and second lower side rails to one another with laterally extending connecting structure comprises:

hydroforming said connecting structure as a U-shaped cross structure;

connecting a first end of said cross structure to said first lower side rail; and

connecting a second end of said cross structure to said second lower side rail.

21. A space frame for a motor vehicle, comprising:

a pair of longitudinally extending, laterally spaced lower side rails;

a hydroformed tubular cross structure connected at opposite ends thereof to an associated one of said lower side rails, said cross structure extending upwardly from a first of said opposite ends thereof so as to form a first pillar of said space frame, said cross structure having a laterally extending portion extending across said space frame, said cross structure extending downwardly from said laterally extending portion towards a second of said opposite ends thereof so as to form a second pillar of said space frame, said hydroformed tubular cross structure thus defining a length between said pillars of said space frame; and

laterally extending connecting structure constructed and arranged to connect said lower side rails to one another.

22. A space frame for a motor vehicle comprising:

a vehicle cage formed from a plurality of hydroformed tubular members,

said hydroformed tubular members including a pair of upper longitudinal structures, each forming an A-pillar of said space frame and each including longitudinal portions extending rearwardly from said A-pillar to an upper end of a rearward-most pillar of said space frame; and

a front end assembly including a pair of upper longitudinally extending members, each having a rearward end thereof fixed to an associated one of said A-pillars.

23. A space frame for a motor vehicle according to claim 22, wherein said pair of upper longitudinally extending members of said front end assembly are hydroformed tubular structures which are fixed to said associated one of said A-pillars by a welded connection.

24. A space frame according to claim 22, wherein said vehicle cage comprises a first pair of laterally spaced, longitudinally extending lower side rails, and wherein said front end assembly comprises a second pair of laterally spaced, longitudinally extending side rails, said first pair of side rails and said second pair of side rails being fixed to one another, and wherein each of said side rails are tubular hydroformed structures.

25. A space frame for a motor vehicle, comprising:

a first longitudinally extending lower side rail, and a second longitudinally extending lower side rail, said lower side rails being laterally spaced from one another;

a pair of longitudinally extending portions constructed and arranged to support a roof of

the motor vehicle;

a plurality of vertically extending structures, each extending between one of said side rails and an associated one of said longitudinally extending portions, said vertically extending structures constituting pillars of said space frame; and

a rear aperture ring connected with rearward ends of said longitudinally extending portions and rearward ends of said lower side rails, said rear aperture ring comprising first and second U-shaped members, each of said U-shaped members being of a tubular, hydroformed construction, wherein each leg of said first U-shaped member is connected with an associated one leg of said second U-shaped member to define a rear aperture of said space frame.

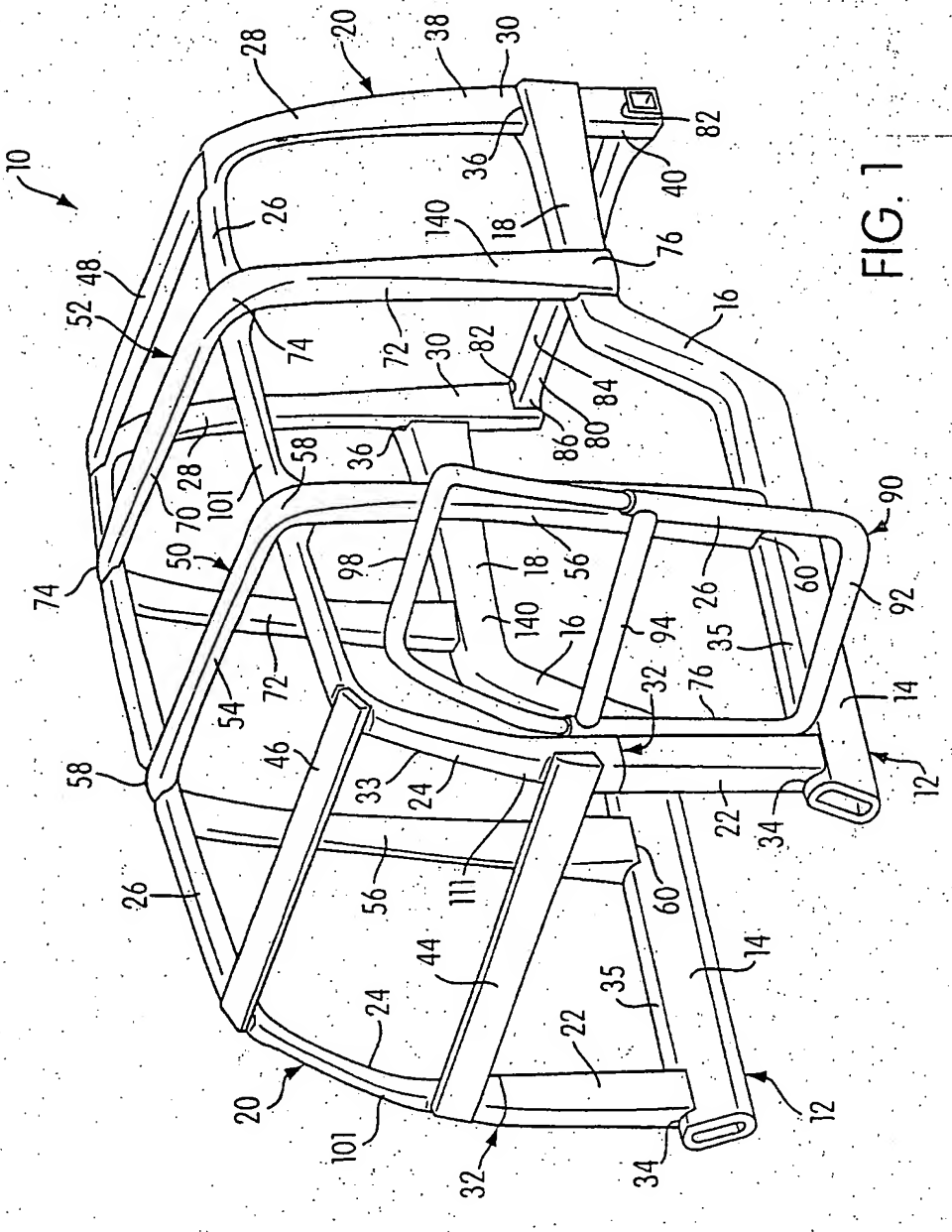
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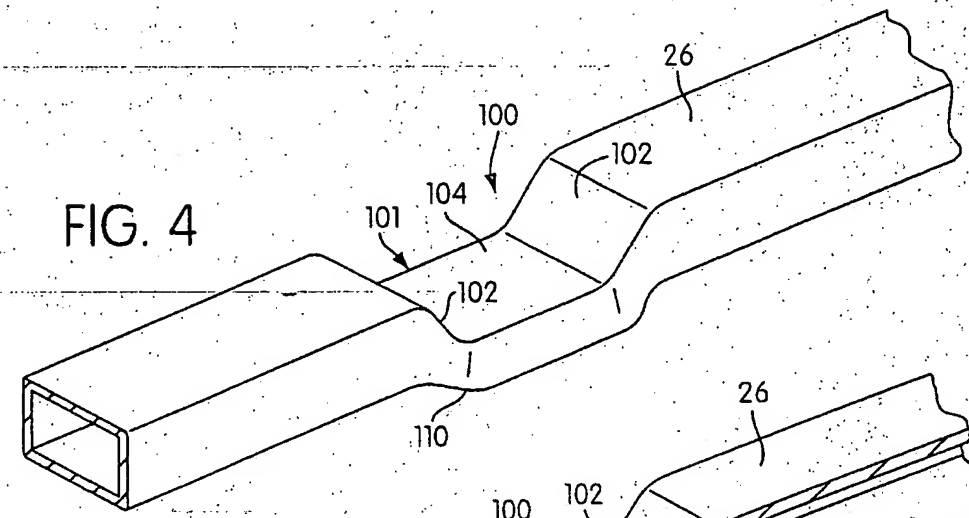
FIG. 1

FIG. 4



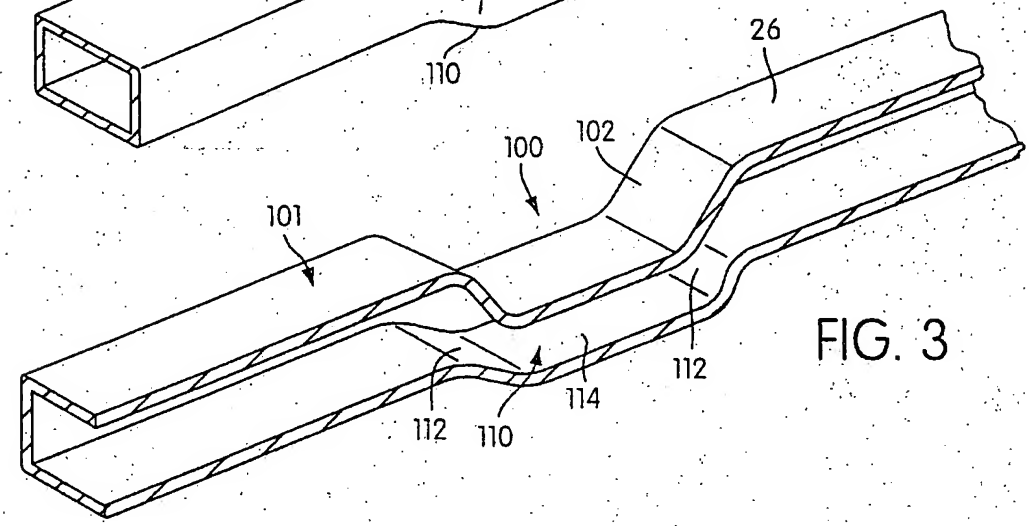


FIG. 3

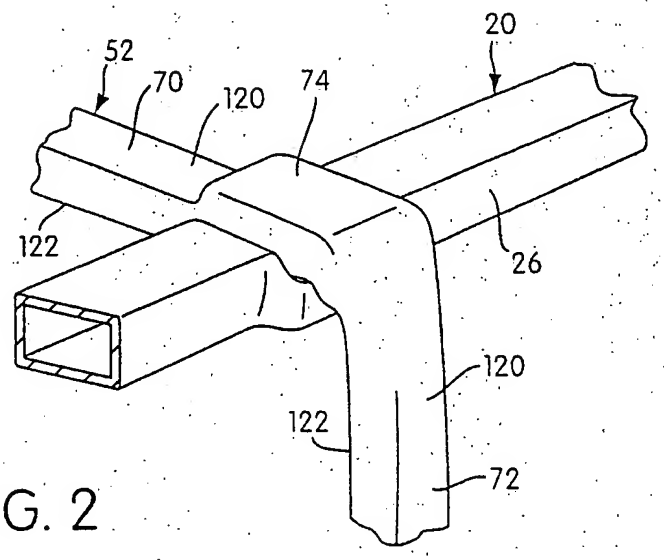


FIG. 2

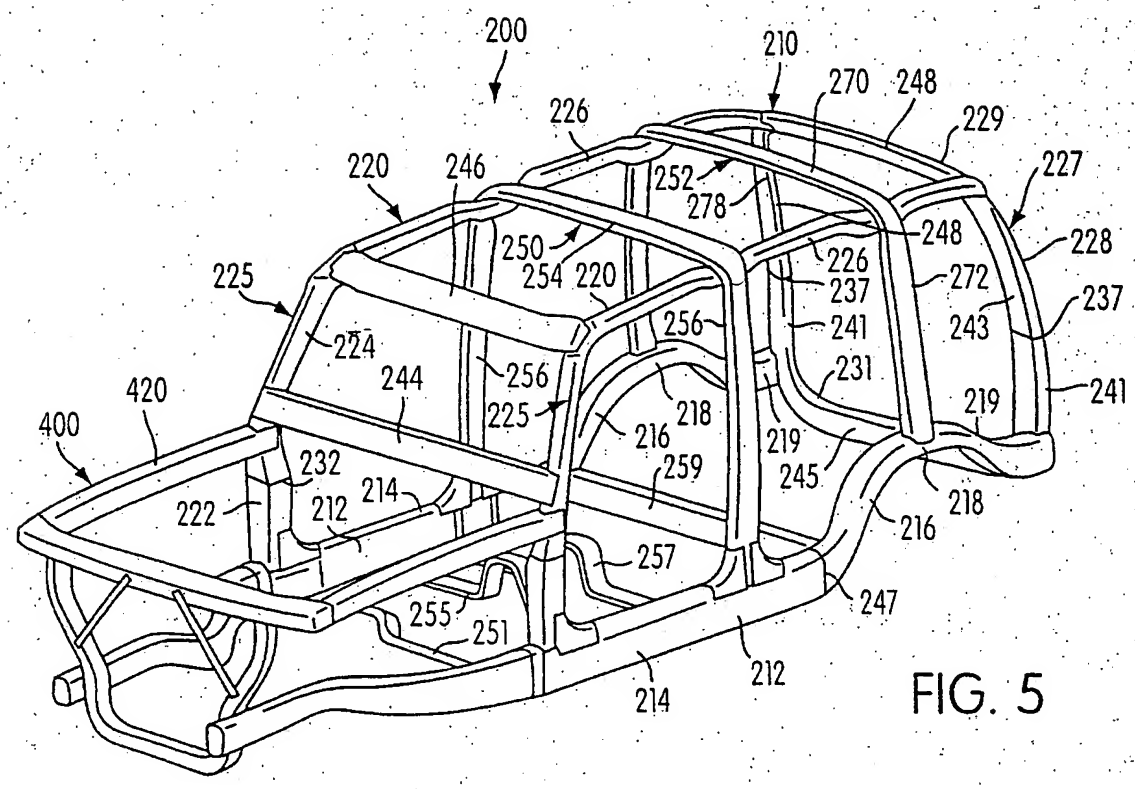

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FIG. 5

FIG. 6

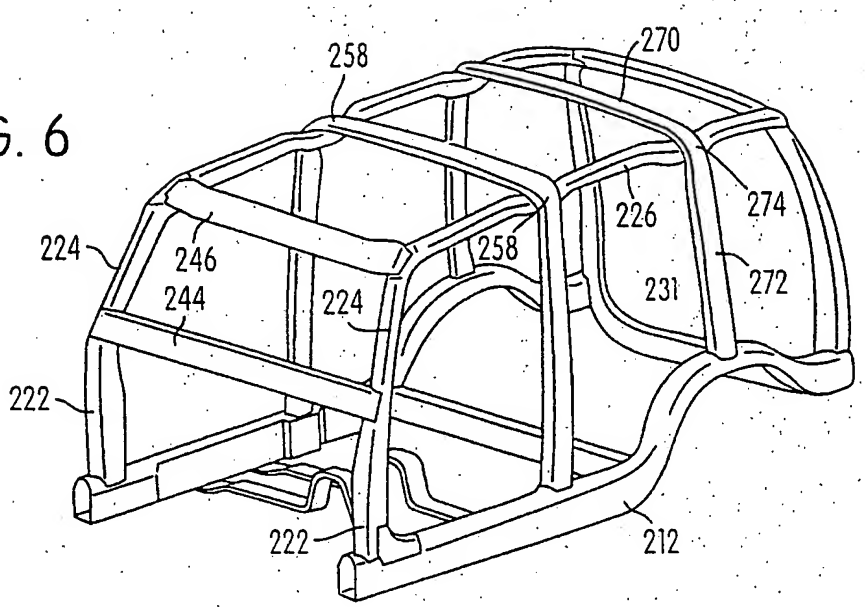
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FIG. 7

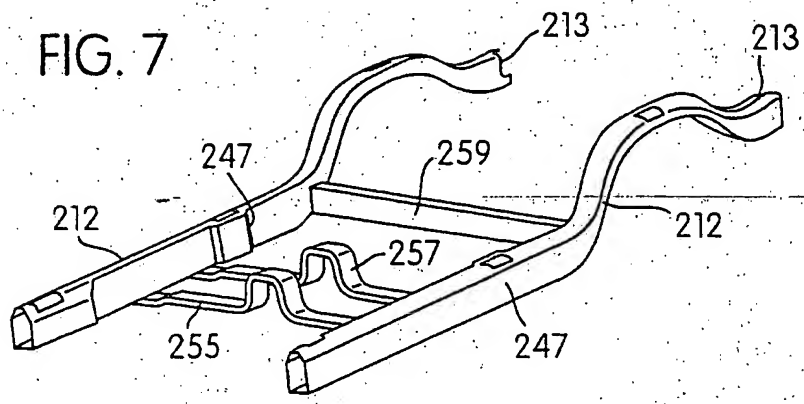


FIG. 8

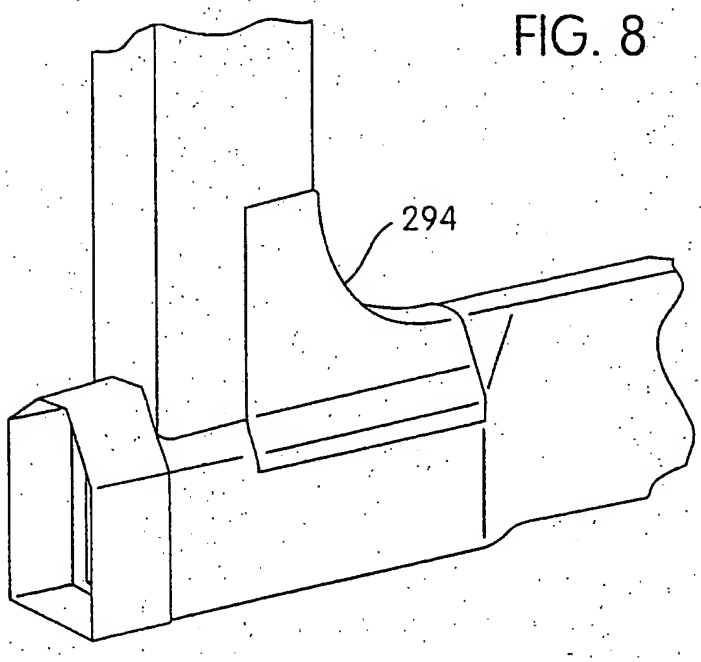


FIG. 10

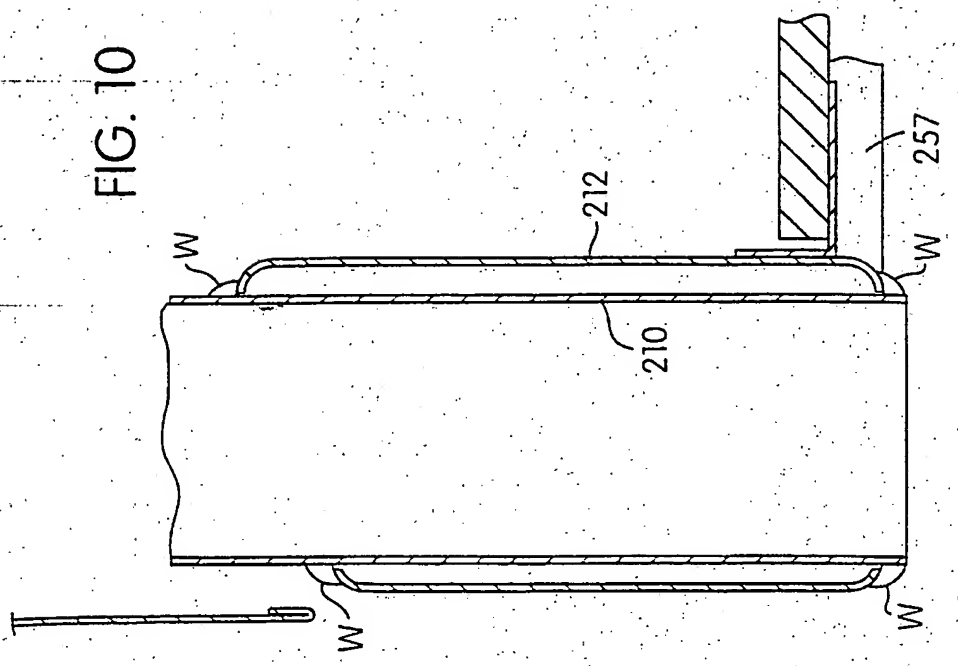
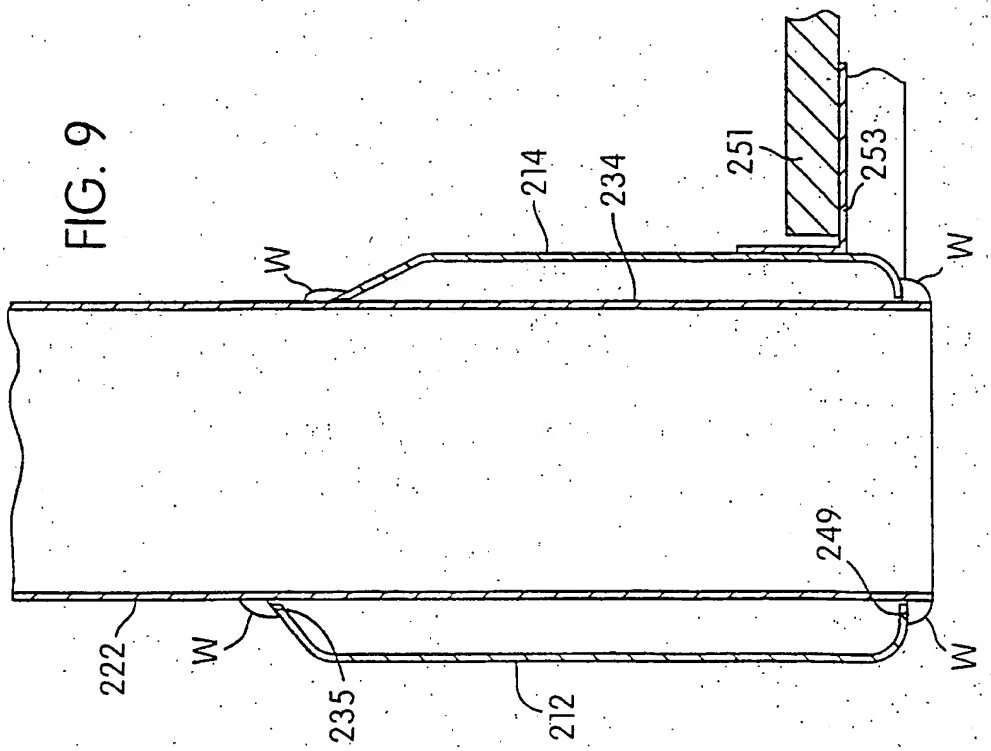


FIG. 9



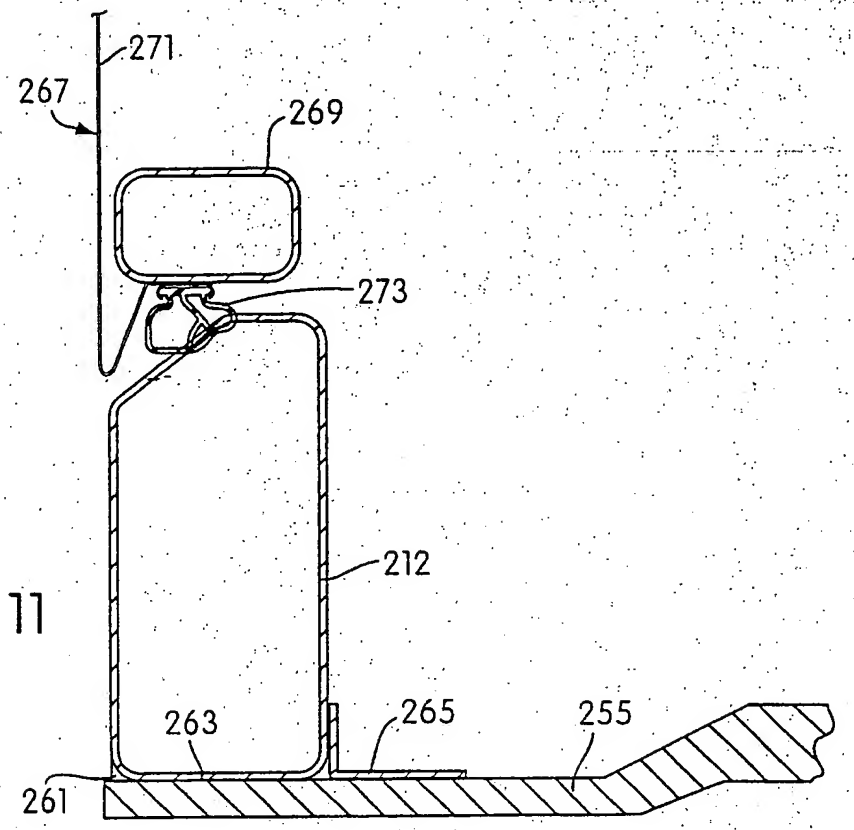


FIG. 11

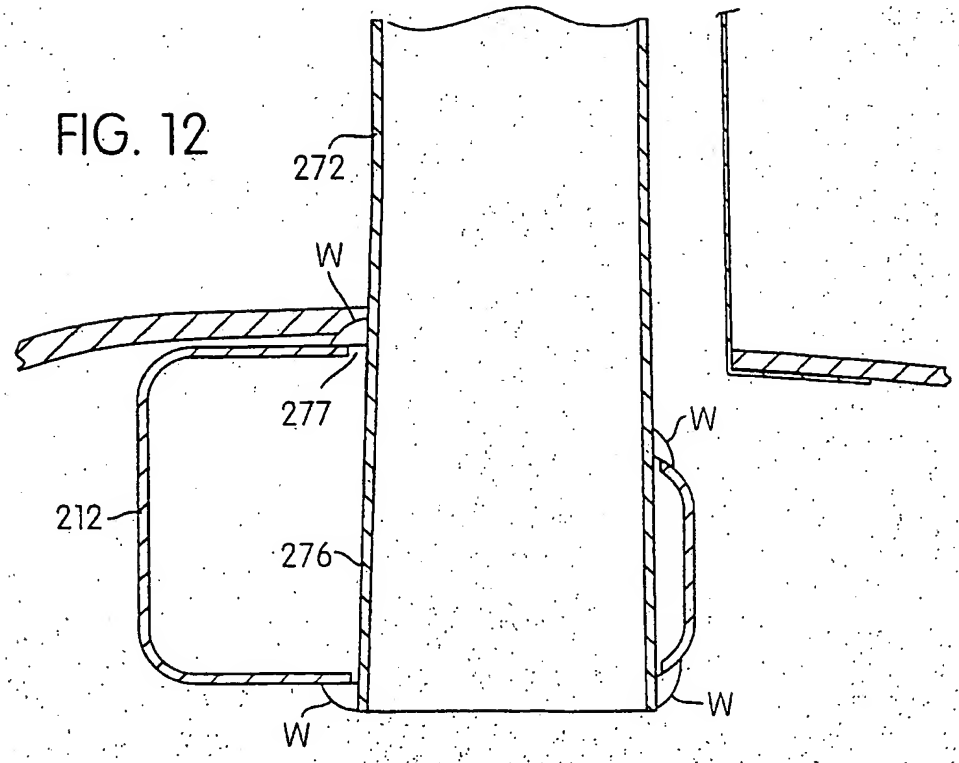
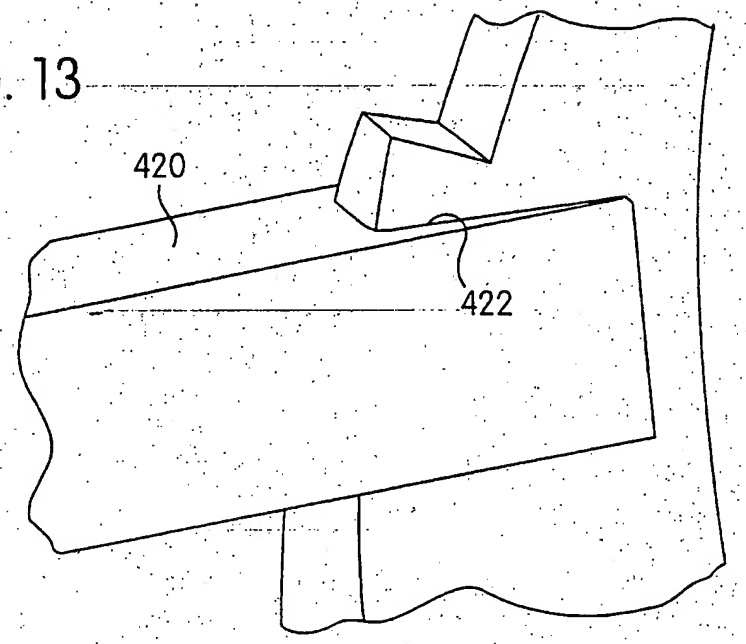


FIG. 12

FIG. 13



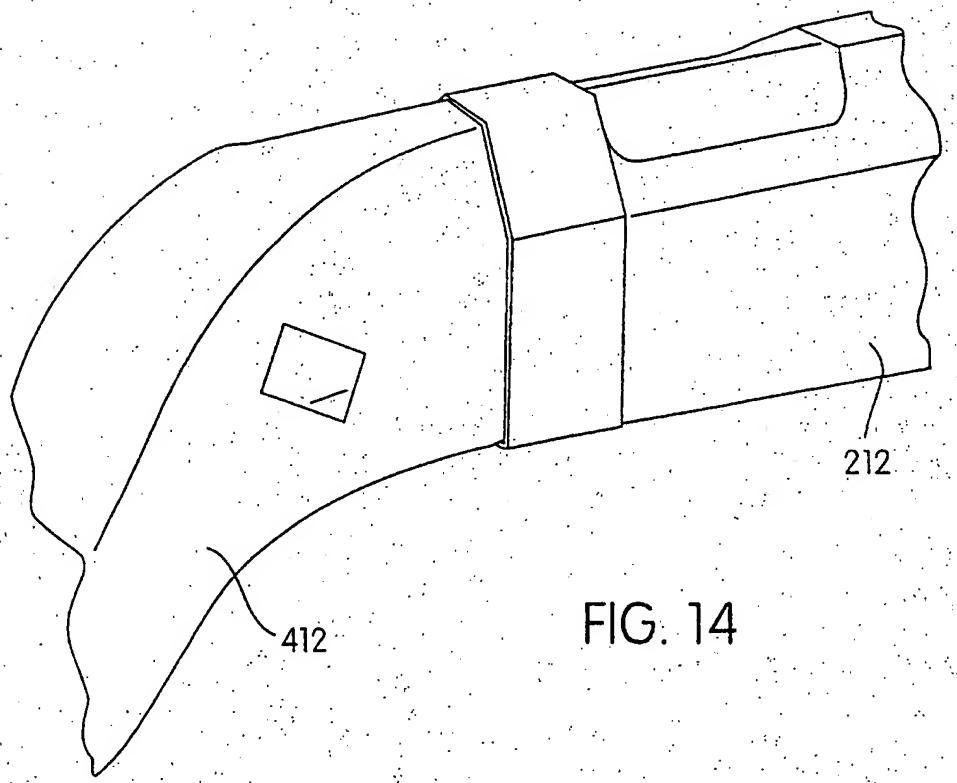


FIG. 14

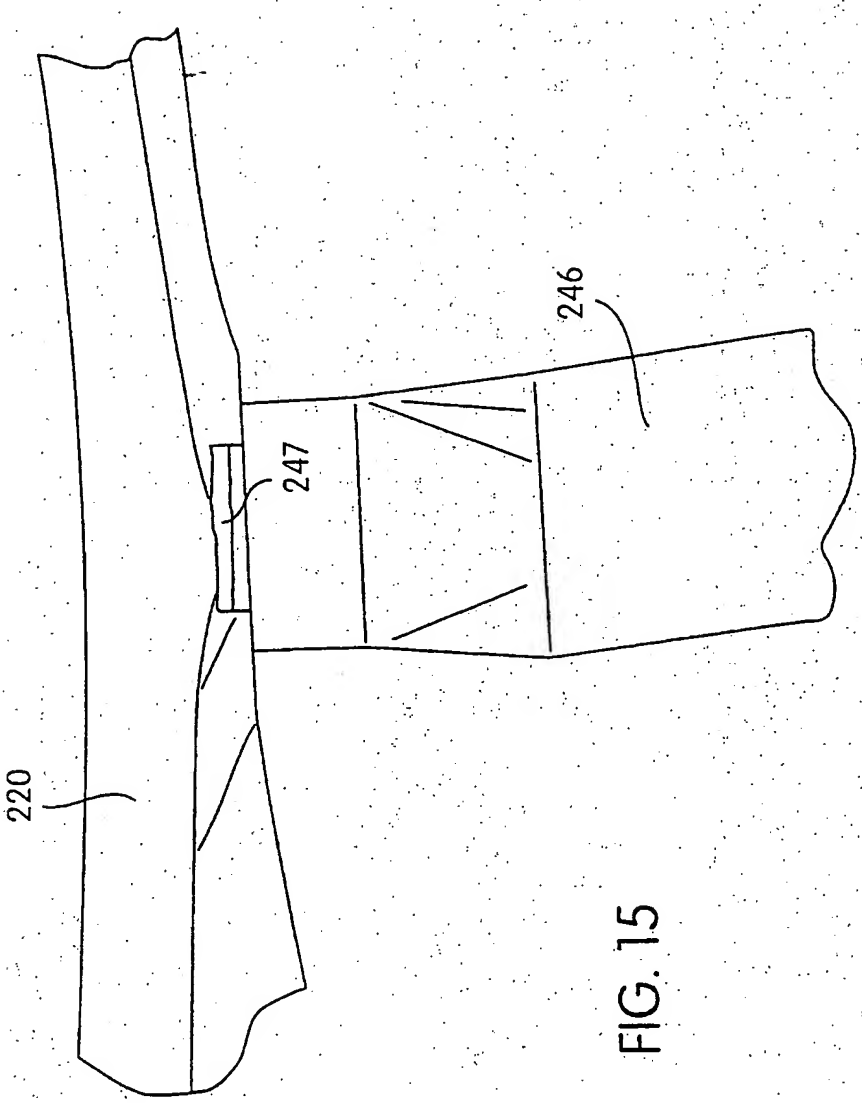


FIG. 15

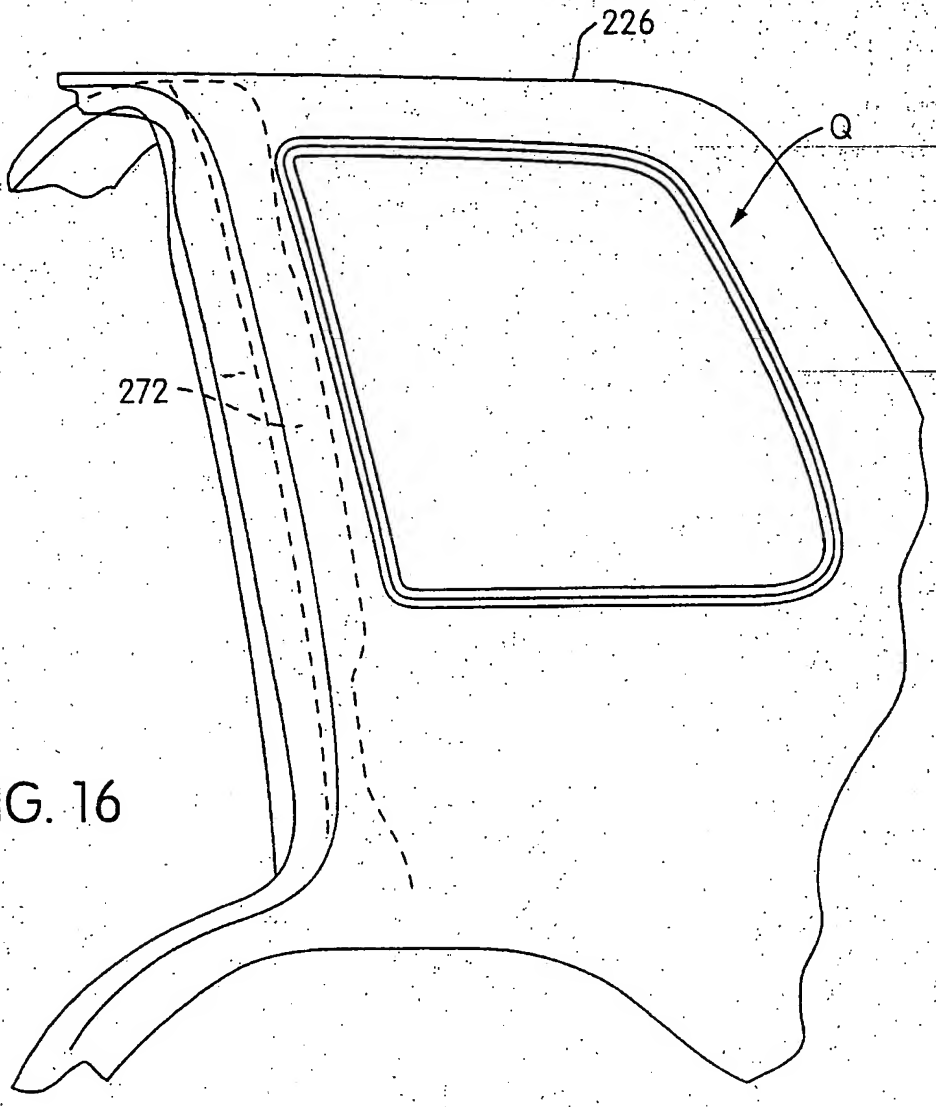


FIG. 16

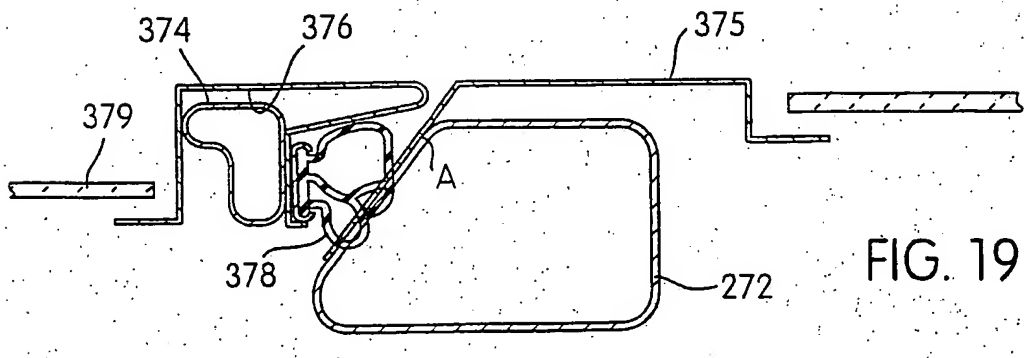


FIG. 19

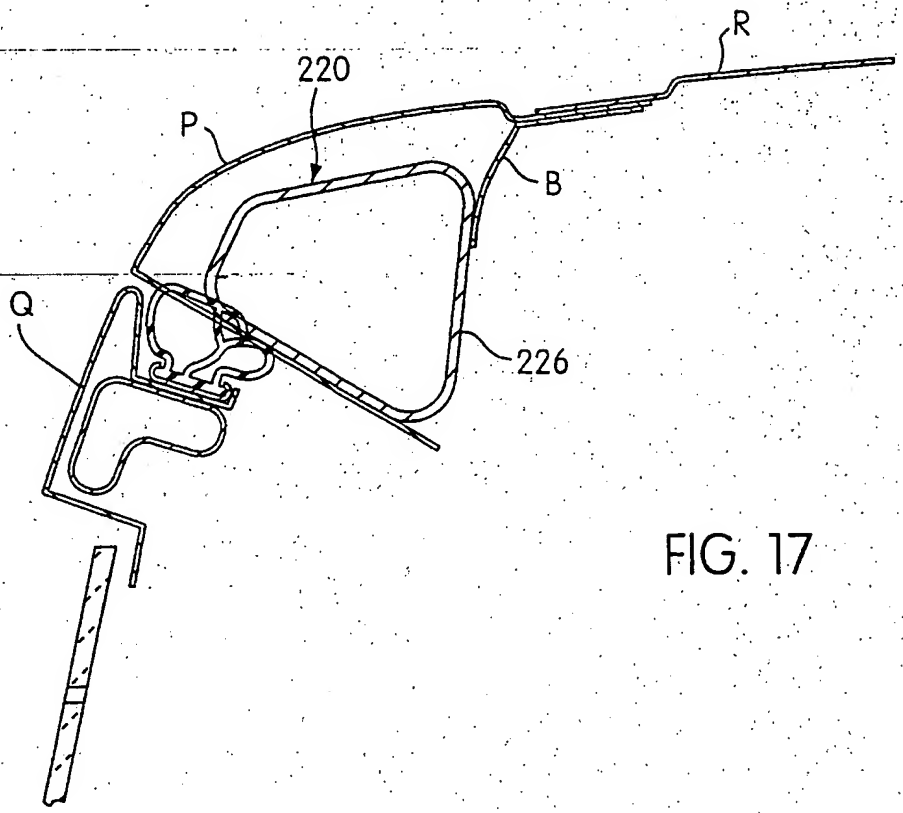


FIG. 17

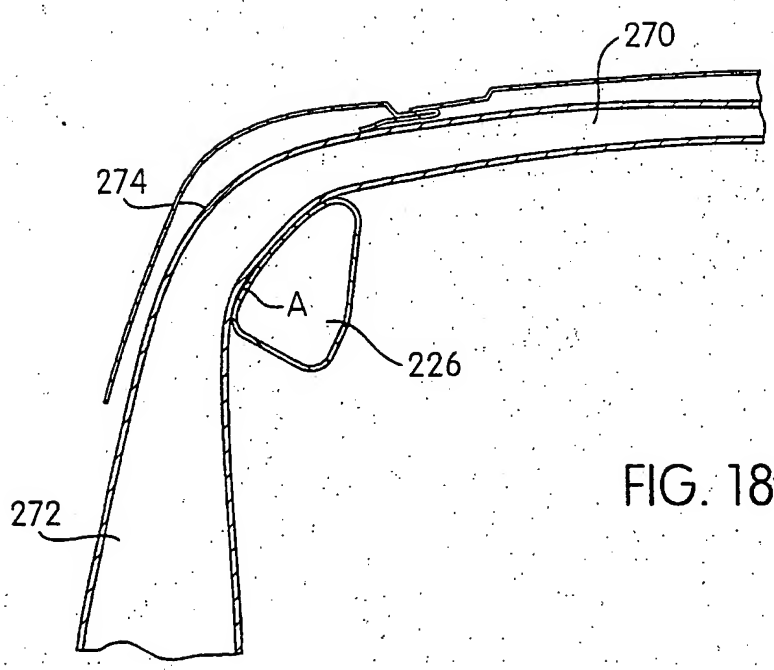


FIG. 18

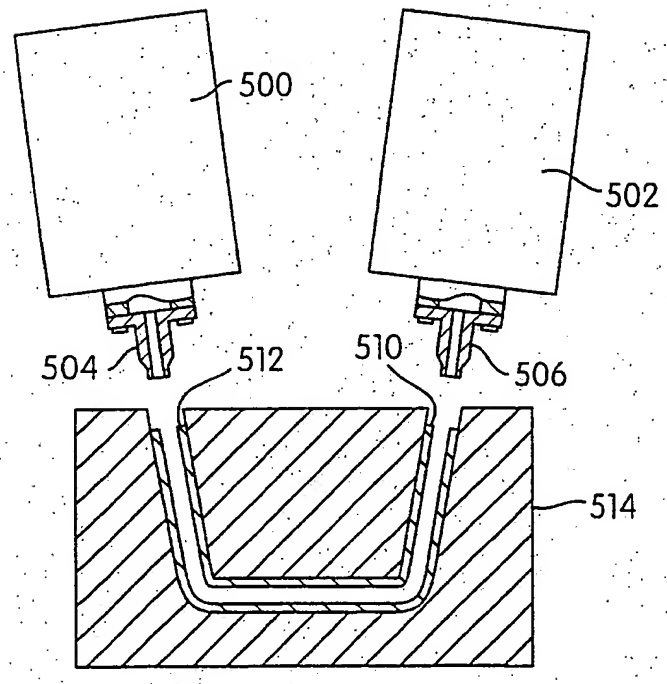


FIG. 20

INTERNATIONAL SEARCH REPORT

International Application No
PCT/CA 98/00962

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 B62D23/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 B62D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2 668 722 A (DAIMLER-BENZ) 9 February 1954 see column 4, line 49 - column 5, line 8; figure 1 ---	1,10-13, 18,22-24
Y	WO 97 00595 A (DANA CORP) 3 January 1997 see page 14, line 23 - page 16, line 3; figures 12-18 ---	1,10-13, 18,22-24
A	EP 0 570 150 A (FORD MOTOR CO ;FORD WERKE AG (DE)) 18 November 1993 see column 2, line 8 - line 18; figure 1 ---	2
A	FR 694 774 A (FERNANDEZ) 6 December 1930 see page 2, line 66 - line 73; figure 1 ---	7

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 February 1999	17/02/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Hageman, L

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International Application No
PCT/CA 98/00962

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category ³	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 649 735 A (TOMFORDE JOHANN ET AL) 22 July 1997 see column 2, line 16 - line 49; figure 1	1
A	DE 867 059 C (AUTO UNION) see page 2, line 35 - line 55; figure 1	1

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

national Application No
PCT/CA 98/00962

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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